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A study of the $\eta\pi^+\pi^-\pi^0$ system centrally produced in pp interactions at 450 GeV/c

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The purpose of this thesis is to search for a hybrid meson state which has an exotic quantum number $J^{PC} = 1^{-+}$ in the $f_1(1285)\pi^0$ system produced in the pp central production process

$$pp \to p_f X^0 p_s,\ X^0 \to f_1(1285)\pi^0,\ f_1(1285) \to \eta\pi^+\pi^-,$$

at 450 GeV/c incident proton beam momentum from CERN SPS observed by the WA102 experiment.

The hybrid meson state is a bound system of a $q\bar{q}$ pair and a valence gluon. The existence of such hadronic states with extra gluonic degree of freedoms is predicted by the presence of the self-interaction of gluons, which is a natural consequence of the non-Abelian nature of Quantum Chromodynamics (QCD). The non-Abelian nature of QCD is essential to a successful explanation for characteristic behavior of the strong force, such as "*asymptotic freedom*" and "*infrared slavery*", but it has not been proved experimentally so far. The observation of hybrid states would give a direct proof of this primary of QCD.

The analysis of the $f_1(1285)\pi$ channel is strongly motivated by the prediction of the flux tube model: the model predicts that the hybrid state with $J^{PC} = 1^{-+}$ will preferentially decay into the $f_1(1285)\pi$ channel. The $J^{PC} = 1^{-+}$ quantum number is not allowed for ordinary $q\bar{q}$ pairs, therefore the observation of the resonant state with 1^{-+} leads to confirmation of the existence of the non-$q\bar{q}$ state unambiguously. Currently three previous experiments reported the observation of the 1^{-+} wave through the partial wave analysis in the $f_1(1285)\pi$ system obtained from the $\pi^- p$ diffractive reaction. They observed that the 1^{-+} intensity was distributed around 2.0 GeV/c^2, which is in good agreement with the model prediction for the hybrid mass. Thus the 1^{-+} wave in the $f_1(1285)\pi$ channel is considered to be the best candidate of the hybrid meson at present. However, its assignment as a hybrid state has not been confirmed because of difficulty to observe the phase motion of the 1^{-+} wave due to its rather broad observed width and a lack of any well-established state in the $f_1(1285)\pi$ channel which is needed as a reference state for the observation of the phase motion. In order to disclose the nature of the 1^{-+} wave in the $f_1(1285)\pi$ channel, more data from different reactions appear to be needed.

The central production process is believed to be one of "gluon rich" processes, where gluonic exotic states are expected to be produced preferentially. In the reaction, both of the beam and target proton exchange particles and form the neutral meson system X^0. The subscripts f and s represent that the beam and target proton are scattered as the fastest and slowest particle in the laboratory frame, respectively. As the center-of-mass energy of the reaction becomes higher, Pomeron exchange is considered to dominate the reaction and hence formed X^0s are thought to have gluonic content more hopefully. Therefore if the 1^{-+} wave observed in the $f_1(1285)\pi$ channel is really a hybrid state, it is expected to be produced dominantly in the central production process.

In the experiment, the fast and slow proton and charge particles in the final state were measured by the Omega spectrometer which is composed of a superconducting magnet with

a central field of 1.35 T, and gammas from decays of neutral particles were detected by the hodoscope electromagnetic calorimeter GAMS. GAMS consists of 64 × 64 lead glass matrix cells and measures detected positions and energies of gammas. The experimental trigger was designed to reject the pp elastic scattering and target diffraction process, both of which dominate the central production process. Through 90 days in 1995 run and 95 days in 1996 run, total 5×10^8 events were obtained.

Various offline cuts were applied and finally total of 1811 events were selected from the 1995 and 1996 data as centrally produced $f_1(1285)\pi^0$ candidates. In order to obtain the spin parity of the observed system, the partial wave analysis (PWA) based on the maximum likelihood fit method was attempted. The decay amplitude of the system was represented by the spin-orbit (LS) scheme using spherical harmonics, assuming two isobars, $f_1(1285)/\eta(1295)$ in the $\eta\pi^+\pi^-$ system for the primary decay and $a_0^{\pm}(980)$ in the $\eta\pi^{\pm}$ system for the secondary decay. All decay angles were with respect to the exchanged particle axis. Data samples of the 1995 and 1996 runs were combined by taking into account the difference between detector acceptances, and were included in the fit simultaneously. To stabilize the fit, the combined data sample was divided into three 0.4 GeV/c^2 mass bins from 1.4 to 2.6 GeV/c^2.

The result of the PWA showed that a combination of exotic 1^{-+} waves of $f_1(1285)\pi^0$ and $\eta(1295)\pi^0$ was best fitted and gave about 3σ larger likelihood than other combinations in the 1.8–2.2 and 2.2–2.6 GeV/c^2 regions. On the other hand, any combination did not have a significantly larger likelihood than the others in the 1.4–1.8 GeV/c^2 region. Especially the 1^{++} wave, which was observed dominantly at $\sim$ 1.7 GeV/c^2 in all three previous $\pi^- p$ diffractive reaction experiments, had only a considerably smaller likelihood in any mass bin.

In conclusion, only the combination of the exotic $f_1(1285)\pi^0$ and $\eta(1295)\pi^0$ 1^{-+} waves was observed with a significant likelihood difference. As it was impossible to see the phase motion of waves due to the limited statistics, it cannot be concluded that the 1^{-+} waves are resonant states. However, it is considered that the clear appearance of the exotic 1^{-+} wave in the "gluon rich" central production suggest the hybrid nature of the 1^{-+} wave in the $f_1(1285)\pi$ channel.

1.4–1.8 GeV/c^2

$0^{-+}\eta 0 + 2^{-+}f_1 1$	0
$1^{-+}f_1 1 + 2^{-+}f_1 1$	−0.1
$1^{-+}f_1 1 + 1^{-+}\eta 1$	−0.7

1.8–2.2 GeV/c^2

$1^{-+}f_1 1 + 1^{-+}\eta 0$	0
$1^{-+}f_1 1 + 0^{-+}\eta 0$	−3.8
$1^{-+}f_1 1 + 2^{++}f_1 2$	−3.8

2.2–2.6 GeV/c^2

$1^{-+}f_1 1 + 1^{-+}\eta 0$	0
$1^{-+}\eta 0 + 2^{-+}f_1 0$	−4.4
$1^{-+}f_1 1 + 2^{-+}f_1 0$	−4.5

J^{PC}[isobar]$|J_z|$
$\eta \ldots \eta(1295)$
$f_1 \ldots f_1(1285)$

Table: Likelihood difference ($\Delta\mathcal{L}$) relative to that of the best fit combination in each mass bin.

Fig.: (a)Total events and estimated backgrounds from the fit. The ratio of signals to backgrounds is well reproduced. (b)Partial wave intensities for the best fit combination in each mass bin.